The Proposed Colorado River Developments

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THE Colorado River is a muddy stream that constitutes the lifeblood of the Pacific Southwest, the most important feature of which is the ultimate scarcity of its water or its ultimate inability to supply the potential needs of the communities dependent on it for irrigation and domestic water supply. The next feature of importance is the potential power capability of the river and its relation to the power needs of this same Pacific Southwest area.

The interests of Nevada in the Colorado River are represented by some relatively small allocations of water for irrigation and in having sufficient electric power to develop the natural resources of the state, and to take care of the natural growth of power needs of the state. Arizona's interest in the Colorado River is to provide for a supplemental supply of water for recently developed irrigated lands which now are making an overdraft on the underground reservoir and to provide for some expansion of agricultural development. Arizona also has an interest in preserving the extensive present irrigation developments on the Salt River and Gila River, which are a part of the Colorado River basin and are related intimately to its water problems. Arizona, also, has a need to obtain sufficient electric energy to supply its normal increase in power demands.

Approximately one-half of California is partly or wholly dependent on the Colorado River for a water supply for irrigation, domestic, and industrial purposes, and also looks to the Colorado River for a substantial part of its electric power supply with consequent saving of more than 15 million barrels of oil annually. As a

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consequence of contracts consummated on the occasion of the construction of Hoover Dam, approximately one million acres of land in the Palo Verde, Imperial, and Coachella Valleys are dependent on the Colorado River for irrigation and domestic water supply. Approximately one-half of this land is developed at present.

Looking toward the formulation of a plan for comprehensive development, the "Comprehensive Report on the Colorado River" presents for consideration "134 potential projects or units of projects, mostly multiple purpose, for use of water within the natural drainage basin of the Colorado River. Potential projects for the export of water from the Colorado River basin to adjacent basins are also discussed."

Important engineering and economic features of the proposed Colorado River developments will determine which of the 134 projects are built. Co-ordination of the use of water in the entire basin is necessary if the best and most necessary use is to be made of the river's resources.

Figure 1 shows a simple map of the upper and lower basins of the Colorado River. The river flows for a distance of approximately 1,400 miles in a southwesterly direction from the Rocky Mountains to the Gulf of California. The drainage basin includes an area of 242,000 square miles within the United States, which is 1/12 of the entire area of the United States.

The river basin includes extremes of year-round snow cover in the Rockies and extreme desert conditions in the Yuma area. Maximum precipitation in the basin, from 15 to 30 inches annually, is found in western Colorado. The second area of heaviest rainfall is found in central Arizona where the annual precipitation ranges from 10 to 20 inches. The portions of Wyoming and Utah within the basin provide precipitation ranging from 5 to 15 inches per year, and the extreme southern desert portion has an annual precipitation of approximately 5 inches per year. The average rainfall for the entire basin is approximately 15 inches, and less than 10 per cent of this rainfall appears as actual runoff as virgin flow of the stream.

All of the water of the upper basin funnels into a stretch of the main river near the Utah–Arizona state line. Lee Ferry, Ariz., one mile below the Paria River, has been chosen as the dividing point between the upper and lower basin. Of the long-term average of 16,270,000 acre-feet of water available at this point, approximately one-half is from the Grand River in Colorado, one-third from the Green River, and one-sixth from the San Juan River.

Between Hoover Dam and the Gila River, the inflow from tributaries amounts to more than one million acre-feet, but is offset by evaporation and seepage so that the flow of the Colorado River at the Gila River is only slightly different from that estimated at Lee Ferry. Under virgin conditions the Gila River contributed an average flow of 1,270,000 acre-feet, which brings the estimated virgin flow of the Colorado River at the international boundary up to approximately 17,700,000 acre-feet.

The use of water on present and presently authorized projects in the upper basin, including diversions to adjacent watersheds, is 2,756,000 acre-feet, which represents a duty of approximately 1½ acre-feet per acre of irrigated land. Potential projects, outlined in the report, would increase this use by 6,381,000 acre-feet, leading to a total ultimate consumptive use in the upper basin, if all projects could be built, of 9,136,000 acre-feet.

In the report the use of water on present and presently authorized projects in the lower basin, including so-called diversions to the Imperial Valley area, is 8,500,000 acre-feet. Potential projects outlined in the report would increase this use by 2,560,000 acre-feet, leading to a total depletion of 11,060,000 acre-feet.

Therefore, the total use of water in the basin, if all potential projects were built, would be nearly 20,200,000 acre-feet. In comparison with the flow of the river available after making allowances for the delivery of 1,500,000 acre-feet per year to Mexico, it is evident that the aggregate for the projects exceeds the estimated amount of water available by at least 25 per cent.

If all of the 134 potential projects could be developed, the new land that would be brought into cultivation would be 1,230,810 acres in the upper basin and 303,150 acres in the lower basin, while a supplemental supply would be made available for 504,170 acres in the upper basin and 618,100 acres in the lower basin.

The total hydroelectric development presently in the upper basin is 57,217 kw, of which about 87 per cent is on the Grand River in Colorado. The potential projects in the upper basin would add 1,713,000 kw and develop 9,241,000,000 kilowatt-hours. In 1943 the installed generating capacity in the upper basin was 101,082 kw, with a production of 330,149,000 kilowatt-hours, or less than six per cent of the total potentialities.

The upper basin power plants are not, in general, large ones. The developments on the Green River include 11 plants having a total capacity of 460,000 kw, of which the Echo Park plant of 120,000 kw is the largest. On the Grand River seven plants have a capacity of 228,000 kw of which the largest is Dewey with 140,000 kw. In the San Juan division eight plants have a capacity of 965,000 kw, and the largest is that at Glen Canyon with 400,000 kw and at Dark Canyon with 350,000 kw.

Obviously, if the developments are made, the power must be transmitted out of the upper basin, which involves exceedingly long transmission lines to the markets. Only one of the upper basin power developments, that at Glen Canyon, near the Utah–Arizona state line, is

apparently suitable for supplying the Southern California area. The transmission distance for this project is nearly 500 miles.

The present total hydroelectric development in the lower basin is 1,258,030 kw installed with planned capacity to be added to bring the total to 1,838,000. The potential projects proposed for the lower basin would add 1,945,400 kw and develop 10,205,000,000 kilowatt-hours. The present demand in the area is approximately 2,500,000 kw and is doubling every ten years.

Figure 1. Colorado River basin

It thus becomes evident that the addition of presently planned capacity plus the potential new capacity plus that portion of the upper basin within economic transmission distance represents a gain of nearly 3,000,000 kw, which is less than 15 years' growth. The added energy of 10,000,000,000 kilowatt-hours represents a fuel saving in excess of 15,000,000 barrels of fuel oil per year. An assured market is available for the full potentialities of the lower basin portion of the stream as long as such projects are so planned and so financed that the costs at the market are competitive with steam with due regard to the reliability of delivery and continuity of service.

Before a selection of projects can be made it will be necessary that the seven Colorado River basin states agree upon their respective rights to deplete the water supply of the Colorado River or that the courts apportion available water among them. Each state also will need to select from the potential projects within its boundaries those it desires to have constructed to consume its allocation of water. The many decisions and selections to be made require a vast background of factual information.

Although the figure for total cost cannot mean much at the present time because all the contemplated projects cannot be built, as some of the irrigation projects lack sufficient water, and some of the projects lack sufficient market; nevertheless it is interesting to know that the figure for the construction cost of the total 134 projects is $3,460,497,200. When they are being planned, each project or related group of projects should be analyzed separately for authorization to determine the relation of economic benefits to cost.

POWER PROJECTS FOR SERVING THE LOWER BASIN

The river profile shown in Figure 2 includes those power projects that might be used to supply the Pacific Southwest power market and Table I summarizes the statistics about them.

The uppermost project shown is Glen Canyon. In the "Comprehensive Report" this project is considered as having a reservoir with a storage capacity of 8,600,000 acre-feet. At 182 miles upstream at Dark Canyon, there is contemplated a project with a reservoir having a capacity of 1,400,000 acre-feet. The capacities of the two plants would be 400,000 and 350,000 kw, respectively.

The Department of Water and Power has been making studies of which some contemplated the use of a reservoir at Glen Canyon of 25,000,000 acre-feet at elevation 3,688 feet. The "Bureau of Reclamation Report" mentions the possibility of a reservoir as large as 34,000,000 acre-feet. The fundamental purpose of a large reservoir is to get increased energy output at Glen Canyon as a result of the greater storage and higher head without having to transmit over the prohibitive distances from Dark Canyon. The large reservoir also has tremendous advantage in prolonging the lives of all the downstream plants by retention of silt. A tentative estimate of plant capacity at Glen Canyon with the large reservoir is 655,000 kw.

Considerable exploratory drilling work has yet to be done before a final site selection for the dam can be made. The Department of Water and Power has made available to the Federal Government $60,000 to carry on such explorations.

The Hoover Dam project plant has an installation of 1,030,000 kw. The contracted firm energy during the contract life of the project will average 4,115,000,000 kilowatt-hours per year. The purposes served by the project are flood control, river regulation, irrigation for Imperial and Coachella Valleys and other lower river projects, domestic water for the Metropolitan Water District, recreation, power and limited intergration with other plants on the river, and integration with the plants of the operating agents. The project is self-liquidating, largely through the sale of power, and returns three per cent interest on the government investment.

The Parker project of 120,000 kw makes deliveries presently to Arizona and Imperial Irrigation District. The Metropolitan Water District ultimately becomes the owner of one-half of the plant and will use the energy for pumping water in its aqueduct.

The Davis project of 225,000 kw, which is now under construction, will have a reservoir which will be used to reregulate for irrigation requirements.

The largest of the potential projects is that known as the Marble Canyon–Kanab Creek Project. A 300-foot dam constructed at the Marble Canyon site would divert part of the water from Grand Canyon and deliver it through a tunnel to a generating plant of 1,250,000-kw capacity.

Bridge Canyon Dam is to be located approximately 115 miles upstream from Hoover Dam. The available head is approximately 670 feet. Without upstream storage, the firm capacity will be reduced to about half the output shown in Table I unless the present rights of the power contractors at Hoover Dam to integrate with their own systems are sacrificed to river co-ordination, with Bridge Canyon taking all credit for increase in energy output of the combined plants.

The average amount of silt reaching Lake Mead is stated to be 137,000 acre-feet per year. The amount reaching the Bridge Canyon site is only slightly less than this. From this it becomes evident that unless other upstream and tributary stream storage is provided, Bridge Canyon would be silted up in slightly over 25 years. The Bridge Canyon project, exclusive of any irrigation features, is estimated to cost $234,400,000.

Bridge Canyon has been incorporated with the Central Arizona project in a recent bill submitted to the United States Senate and on which hearings were held recently.

In view of the fact that there is not enough water available to permit construction of all of the potential projects, the regional directors, in presenting their report, make the following recommendations:

1. That the states of the Colorado River basin, acting separately or jointly, recommend for construction, as the next stage of development, a group of projects, the stream-flow depletions of which assuredly will fall within ultimate allocations of Colorado River water which may be made to the individual states.

2. That the states of the Colorado River basin determine their respective rights to deplete the flow of the Colorado River consistent with the Colorado River Compact.

3. That additional investigations and appropriations to the Department of the Interior for use by the various agencies within that department for these investigations, be approved.

Determination of Initial Development. With respect to any of the future developments for power along the Colorado River, the Bridge Canyon project is the nearest to the Pacific Southwest market and obviously has prime consideration as the nearest project to be developed. Presumably, the output figure is dependent on certain other developments being made upstream and does not represent the capability of the project as contemplated in any initial program involving the construction of the Bridge Canyon project only.

A study made by the Federal Power Commission under the direction of E. W. Cramer, dated January 1, 1942, indicated that with upstream depletion of 2,671,000 acre-feet, which is somewhat less than the current depletion, the firm energy output at Bridge Canyon would be 1,840,000,000 kilowatt-hours. Since the Bridge Canyon active storage is only 2,650,000 acre-feet, which will be reduced rapidly by silt encroachment, the firm power capacity will be very sensitive to depletions by the upper basin, and since the depletions will be initially somewhat larger than contemplated in the Federal Power Commission study, the firm energy at Bridge may be even lower than the 1,840,000,000 kilowatt-hours. To some extent the Bridge Canyon project tends to approach the characteristics of a run-of-stream plant.

Figure 3 shows the air-line transmission distances involved in the projects under consideration. If the firm energy from Bridge Canyon as an initial project should prove to be approximately one-half of that indicated in the report, as indicated by the Federal Power Commission's figures, then with transmission-line distances to the Southern California market from Bridge Canyon being in excess of 335 miles, it would not be economically

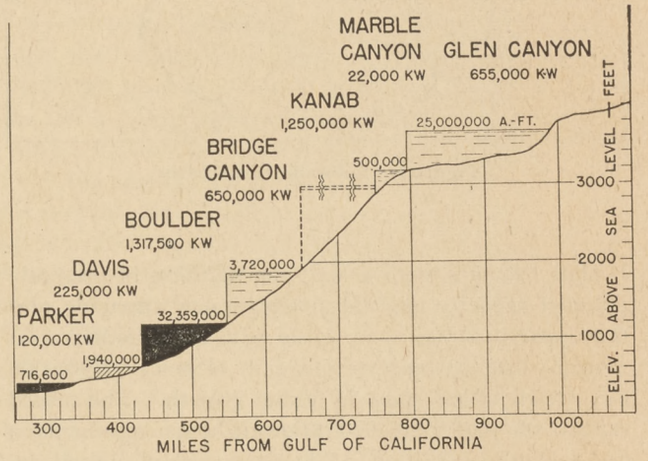

Figure 2. River profile of reservoirs and hydroelectric power plants

attractive to transmit energy where a large percentage of the energy would be essentially only fuel-saving, or secondary energy, instead of firm energy. With this possibility in mind, it seems desirable to the Department of Water and Power to investigate the nature of developments along the Colorado River that should be made initially in order to choose the most economical combination. The three choices that are involved are as follows:

1. Bridge Canyon reservoir and power plant only.

2. Glen Canyon reservoir and power plant only.

3. Bridge Canyon reservoir and power plant plus Glen Canyon reservoir.

Of these three possibilities, the first project requires the least transmission cost but produces a relatively small amount of firm energy. The second project has the greatest transmission cost but develops a relatively large amount of firm energy. The third project involves a large amount of power plant and reservoir investment, but requires a relatively low transmission line investment and develops a relatively large amount of firm energy.

As Glen Canyon power plant is approximately 470 miles from the Southern California market, it does not seem economically feasible to give consideration to any initial program for power developments supplying that market from further upstream than Glen Canyon.

Transmission Considerations. A study of the physical feasibility of such transmission to Los Angeles was made on the network analyzer of the Bonneville Power Administration. Solely for the purpose of calculations, the studies were made on the basis of transmitting the normal peak capacity of the Boulder system of the department, together with 300,000 kw from either Glen Canyon or Bridge Canyon, by using certain transmission line additions in combination with the city's present Boulder–Los Angeles transmission system. Such studies provided for a reduction of ten per cent from the theoretical value of line capability in determining the operating limits.

The most practical systems proved to be those contemplating the addition of a fourth circuit to the existing three Boulder circuits, together with the use of double circuit lines from either Glen Canyon or Bridge Canyon to interconnect with the Boulder system at Hoover Dam. Running the lines by way of the Hoover power plant gave a smaller additional transmission investment and better stability than other alternatives but increased the circuit breaker duty at Hoover power plant.

The combination of the Bridge Canyon or Glen Canyon lines with the present Boulder system augmented by one additional circuit gave lower incremental investments for the same performance and delivery than was obtainable by consideration of separate systems. In all cases the physical feasibility of transmission of these amounts of power was demonstrated.

In these studies, no effort was made to determine precisely either the minimum compensation or the economical compensation that would be desirable for the lines involved. The tests only went sufficiently far to determine that the transmission performance was such as to be considered physically practicable and economically feasible.

It was found that operation of the lines at 287,500 volts was of lower cost and gave better over-all economy than would be obtained by the use of higher voltage lines to produce the same capability.

This study, however, would not take into account the characteristics and use of other upper basin reservoirs, which would affect the problem to some extent. The use of Glen Canyon reservoir served to reregulate the depleted flow so that no special demand had to be made on the upper basin to meet the required 10-year average of $7\frac{1}{2}$ million acre-feet in accordance with the compact. If such a reservoir were not in operation there would be, under ultimate conditions of upper basin use, eight years in a period of ten years when such use of water would have to be reduced to make delivery to the lower basin under the 10-year average requirement of the compact.

In determining the costs for power produced by these individual projects, or in combination, it is necessary to face the formidable problem of allocation of investment

Table I. Power Plant Capabilities of the Lower Colorado River Developments

Power Plant	Installed Capacity, Kw	Average Annual Output, Million Kw-Hr		Capacity, Acre-Ft
		Firm Energy	Secondary Energy	
Glen Canyon	400,000	2,200	533*	8,600,000
				3,000,000
Marble Canyon	22,000	164	32*	500,000
Kanab	1,250,000	6,570	2,360	
Bridge Canyon	650,000	3,440	395	3,720,000
Boulder†	1,317,500‡	4,115	800	32,359,000
Davis**	225,000	750	145	1,940,000
Parker*	120,000	500	100*	716,000
Totals	3,992,500	17,666	4,365	

* Estimated values.

** Under construction.

† Constructed to partial capacity.

Constructed.

‡ Ultimate capacity.

costs to multiple purposes. At this initial stage of consideration, it was neither desirable nor possible for the department to make any comprehensive determination of such allocations. Nevertheless, some tentative allocation is necessary at this time so that the results will not be out of line with those ultimately to be determined.

In this study, no diversion to Arizona was considered at or above Bridge Canyon so all of the investment and expenses of Bridge Canyon development were considered for power purposes.

It was considered that certain parts of the investment at Glen Canyon would be charged to lower river projects profiting thereby, excepting the Hoover project, which, like Glen Canyon, renders service to other projects. In this problem, for simplicity and conservative results, such allocation of Glen Canyon investment was made only to the Bridge Canyon project, although in the future some further allocations might be considered. The allocations assumed for Glen Canyon Dam were as follows:

Flood control.....11.5 per cent
Reregulation for compact.....39.9 per cent

Reregulation for Mexican Treaty	4.4 per cent
Power production at Bridge Canyon	22.7 per cent
Power production at Glen Canyon	21.5 per cent

The figures are highly tentative and in no way reflect what may be the final judgment on an appropriate allocation.

In making the cost study it was found desirable to confine the figures to that portion of the power which possibly might be used in the Los Angeles system, rather than trying to make an estimate for the total output. For this tentative study, it was decided to assign 40 per cent of the capacity, energy, and costs of the power investments at Bridge Canyon and Glen Canyon to the Los Angeles system and deliver corresponding amounts of energy over the transmission system heretofore described. These quantities are lower than the transmission capabilities determined on the network analyzer, that is, 300,000 kw, and are therefore conservative from the viewpoint of costs.

Table II. California Priorities

Order of Priority	Project	Capacity Acre-Ft
1	Palo Verde for 104,500 acres of land;	
2	Federal Yuma project for 25,000 acres	3,850,000
3	Imperial and Palo Verde	
4	Metropolitan Water District	550,000
5	*A*—Metropolitan Water District	550,000
	B—San Diego	112,000
6	Imperial and Palo Verde	300,000
Total		5,362,000

In determining the annual costs for deliveries of power to the City of Los Angeles, the investment in dams and reservoirs allocable to power and the investment for generation was amortized at two per cent over a period of 50 years.

In view of rapidly changing costs and varying possibilities of allocations of investment, it would be premature to report, as a matter of record, actual costs per kilowatt-hour. However, the relative unit costs per kilowatt-hour are indicated in Figure 4. It is sufficient to state that the costs obtained in our preliminary and tentative estimate for Bridge Canyon alone for firm energy is considerably in excess of steam plant unit costs in Los Angeles and would not be attractive. In comparison with this cost, the cost of energy for the project developed at Glen Canyon alone appears to be approximately 70 per cent of such cost, and the cost for the Bridge Canyon development augmented by Glen Canyon storage would be only 60 per cent of the cost of the single development at Bridge Canyon. These results indicate that the costs of the Bridge Canyon development augmented by Glen Canyon storage are sufficiently lower than steam plant costs to make the use of such energy desirable.

There is not sufficient margin in these costs to permit the revenues from power to carry the burden of subsidizing any irrigation projects that might be proposed to be developed concurrently with the power projects which just have been under discussion.

On the basis of the foregoing results, the City of Los Angeles has suggested that the Bureau of Reclamation make a study to determine the initial type of project that should be authorized by the Congress. This will involve such comparisons as have been presented in this discussion.

A further objective of their study would be to determine the economic reservoir capacity to be provided at or near Glen Canyon, taking into account the modifications occurring because of other upper basin storage and the characteristics of flow as a result of their operations. The silt problem probably will point the way to the desirability of relatively large storage at Glen Canyon.

CENTRAL ARIZONA PROJECT

For a period of three years the Bureau of Reclamation has been carrying on investigations of the Central Arizona Project, which have been conducted under an agreement with the state of Arizona.

In this work consideration was given to three alternative projects:

1. The Marble Canyon route, wherein water would be diverted from the proposed Marble Canyon reservoir, through 143 miles of continuous tunnel to discharge into the Verde River, and finally be delivered at Granite Reef Dam on the Salt River.

2. The Bridge Canyon route, wherein water would be diverted from the Bridge Canyon reservoir, through a 78.5-mile continuous tunnel to the Big Sandy River, and thence by 235 miles of aqueduct and 11 short tunnels totaling 13.7 miles to the Granite Reef Dam.

3. The Parker route, wherein water would be pumped from Havasu Lake at Parker Dam, through four lifts totaling 985 feet, and thence flowing by gravity through 235 miles of aqueduct to Granite Reef Dam. The diversions contemplated were uncertain but ranged from one to two million acre-feet.

Provisions of Bill. In April 1947, Senator McFarland of Arizona introduced a bill in the United States Senate (*S.1175*) authorizing the construction, operation, and maintenance of a dam and incidental works in the main stream of the Colorado River at Bridge Canyon, together with certain appurtenant dams and canals for other purposes. Under the detailed provisions of this bill the Secretary of the Interior is authorized to construct, operate, and maintain:

1. A dam and incidental works at Bridge Canyon.

2. A tunnel and main canal from Bridge Canyon to Granite Reef Dam together with necessary distribution canals.

3. Power plant and transmission lines for the fullest development of electric energy from the works.

4. Numerous dams and incidental works, above Bridge Canyon and on various tributaries of the Gila River in Arizona and New Mexico for the successful operation of the project.

Provision was made, however, that construction of the tunnel and portion of the canal shall be deferred until Congress appropriation indicates that it has determined that economic conditions justify its construction. To provide means of diversion of water from the Colorado River to the main canal pending the construction of the tunnel and portion of the canal and for use thereafter as supplemental and stand-by works, the Secretary of Interior is authorized to construct, maintain, and operate from appropriations authorized by the act an aqueduct from Lake Havasu to and connecting with the main canal in the vicinity of Cunningham wash and pumping plants to raise the water from Lake Havasu to such elevation as may be required to provide gravity flow of the water from Lake Havasu to the main canal.

V. E. Larson, assistant regional planning engineer for Region III of the Bureau of Reclamation, in a testimony stated:

> The stage has now been reached where almost one-half of the total water applied in the area is pumped. During the period, 1940–1944, this excess withdrawal averaged about 468,000 acre-feet a year. As a result ground water levels are dropping progressively.

Comment should be made to the effect that despite this shortage and profligate use of underground water, Arizona has not passed any regulations regarding use of underground waters and has permitted the exploitation of such water during a period of high crop prices, where those who embarked on this venture of mining water, were doing so with the full knowledge that it was short-lived but presumably well worth the cost. Whether such farms have to be "rescued" is the problem.

Larson continued,

> On June 18, 1946, Senator McFarland introduced for consideration by the United States Senate, Bill *2346* (later superseded by *S. 1175*), for the purpose of authorizing construction of the Central Arizona project on the basis of the Bridge Canyon route. Significant among its provisions were modifications of the existing Reclamation Law to extend the repayment period for costs allocated to irrigation from 40 to 80 years, and to reduce the interest rate for costs allocated to power from 3 to 2 per cent.
>
> The Bureau report affirmed previous contentions that the Central Arizona project is essential to sustain the existing economy in the area and that it is feasible from a construction standpoint. However, operation of the project would not provide sufficient revenue from power and irrigation to repay the construction costs allocated to the benefits in accordance with present Reclamation Law. Full repayment within the fixed time limits would require a power rate such as would preclude the sale of electric energy.

The report covered both the Bridge Canyon and Parker routes and indicated that:

> Either route could be constructed under modern engineering and construction methods, and that the preponderance of advantage lies with the Parker route, because of its lower total cost, shorter construction time, and greater economic feasibility.

Costs, Revenues, and Returns. In round numbers the cost of the entire Central Valley project as described in the present Senate bill *S.1175*, including the aqueduct from Bridge Canyon, is $1,011,500,000. It does not seem reasonable that such ever would be built, so consideration will be given only to the figures quoted for the Parker route project. The total cost of this project is nearly $605,000,000 made up as follows:

Bluff Dam and reservoir	$ 25,700,000
Coconino Dam and reservoir	$ 6,400,000
Bridge Canyon Dam and reservoir	$164,200,000
Bridge Canyon power plant	$ 60,800,000
Havasu pumping plants	$ 20,500,000
Granite Reef aqueduct	$107,400,000
Central Arizona Works	$133,600,000
Power transmission system	$ 86,100,000
Total	$604,700,000

The annual cost for operation and maintenance was $5,130,000 with $1,985,000 for replacements.

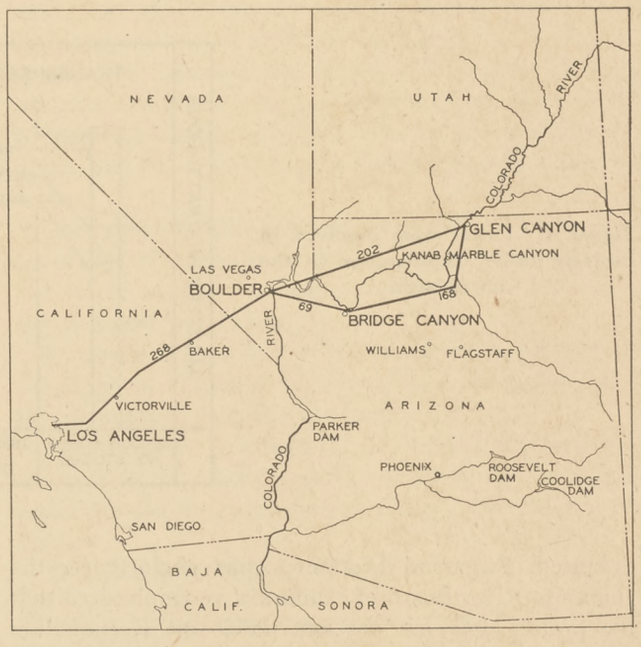

Figure 3. Air-line transmission distances involved in projects under consideration for Los Angeles

A charge to the farmer of $4.50 per acre-foot at the farm headgate is estimated. On the basis of delivery figures given in the statement, it appears that about $3,400,000 per year would be derived from this source. During the first 50-year period, the returns from power on the basis of 4 mills per kilowatt-hour at the market would average about $11,400,000 to produce a total revenue of $14,800,000 annually. Over an 80-year period the annual revenue is estimated to average $14,070,000.

The manner in which these returns are applied to the costs of the project is described in Larson's testimony as follows:

> In all studies, the interest component of the payments made on the power investment is considered as being applicable in aiding the retirement of the irrigation obligation during the power repayment

period. In addition, under provisions of Senate bill *433*, where eretirment of the irrigation investment within an 80-year period is provided for, all net power revenues accruing after the power investment is repaid are applied to the repayment of the irrigation obligation until full repayment of the irrigation construction costs is accomplished.

The estimated average annual costs repayable from project operations, based on April 1946 price levels, would be $13,952,000 under the terms of Senate bill *433*. Net average annual returns would be $14,070,000. This results in a return-to-cost ratio of 1.01 to 1. A power rate of $0.00396 per kilowatt-hour would provide a return-to-cost ratio of 1 to 1.

Under the terms of existing Reclamation Law the estimated average annual costs would be $19,059,400. Net average annual returns would be $14,810,300. The return-to-cost ratio would be 0.78 to 1. In order to effect a return-to-cost ratio of 1 to 1 under the terms of existing Reclamation Law it would be necessary to sell the power at a rate of $0.0055 per kilowatt-hour.

In commenting on the features that just have been discussed, Raymond Matthew, chief engineer for the Colorado River Board of California, re-emphasized that the project does not pay out under the Reclamation Law, and that it is only under the condition that the nonreimbursable items are increased and the repayment for the irrigation items extended from 40 to 80 years, and the power revenues for the entire period used, that the returns are about equal to the estimated annual costs.

On the basis that the interest component on power investment is not applicable to repayment of the capital costs of irrigation, and that such interest component is a necessary part of project costs in addition to repayment of all reimbursable capital costs, operation and maintenance expenses and replacement, Matthew stated:

In order to provide sufficient revenue to secure repayment in 50 years, one of three alternatives would be required:

1. With irrigation water revenue based on $4.50 per acre-foot at farm headgate, the commercial power rate would have to be increased to 7.13 mills per kilowatt-hour at load centers.

2. With commercial power revenues based on 4 mills per kilowatt-hour at load centers, the charge for irrigation water at farm headgate would have to be increased to $18.56 per acre-foot.

3. With commercial power revenues based on 4 mills per kilowatt-hour at load centers and irrigation water revenues based on $4.50 per acre-foot at farm headgate as assumed in the Bureau's report, a capital subsidy from the United States Treasury of $447,545,000 would be required.

Matthew had pointed out that "the cost of operation and maintenance and replacements chargeable to irrigation exceeds the irrigation revenue." In his presentation he indicated that, if, in addition, irrigation was charged with the total cost of its power as an operating expense, the annual charges would be $9.55 per acre-foot for which the farmers would be paying only $4.50.

POWER OPERATIONS

With respect to certain phases of the power development, Larson stated:

Reservoir operation studies for power production have been made by the Bureau of Reclamation on the basis of full co-ordination and integration of the Government plants on the lower Colorado River. It has been assumed that Davis power plant would be completed and that the full designed capacity would be installed in Hoover power plant at the time that Bridge Canyon power plant was completed. In all studies, the amount of water available for power generation has been incidental to river regulation, flood control, and irrigation releases and storage.

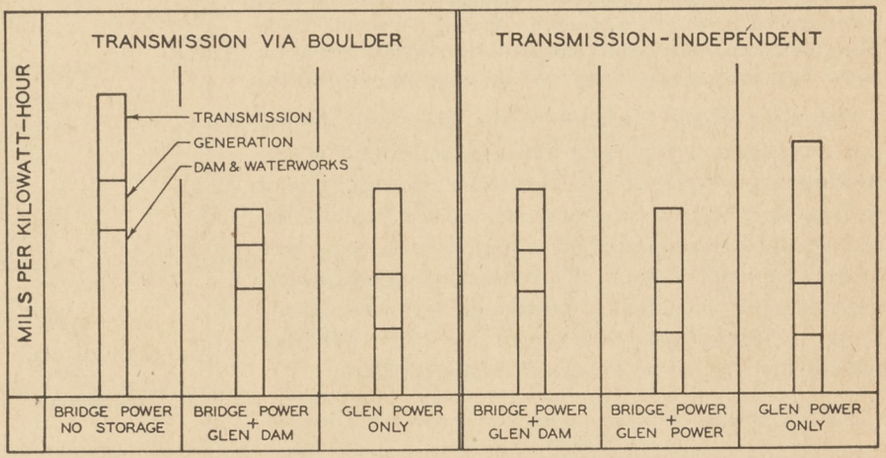

Figure 4. Power costs involved in projects under consideration in the lower basin

Co-ordinated operation of all power plants produces the largest possible amount of firm power. Under this system, the plants with small reservoirs would generate a greater percentage of the total power produced during periods of high runoff than they would in low runoff periods. Concurrently, the other plants with large reservoir capacity could reduce their output and store all possible water for use in low runoff periods. With this system of operation it is possible to produce a higher total system firm energy than under independent operation.

The period 1931 to 1940, inclusive, is taken as a period of low flow of the river and is assumed as the critical period for the reservoir operation studies. These studies were computed for three conditions of development of the Central Arizona project:

1. Initial conditions, assumed to be those resulting at the completion of the construction of the project.

2. Ultimate development, assumed to be 50 years after initial conditions.

3. Average conditions, assumed midway between initial and ultimate development.

The potential output of the Colorado River plants under the co-

ordinated operation . . . is 10,725,000,000 kilowatt-hours of firm energy annually. Of this amount Bridge Canyon is credited with 4,675,000,000 kilowatt-hours, Hoover with 4,500,000,000 kilowatt-hours, and Davis and Parker with a combined total of 1,550,000,000 kilowatt-hours.

The diversion of energy for irrigation pumping ranges from 1,154,000,000 kilowatt-hours in the early years to 1,633,000,000 kilowatt-hours in the latter years. The net average generation available from the energy credited to Bridge for sale to the potential market is 3,070,000,000 kilowatt-hours.

The comprehensive development including Glenn Canyon affords an excellent opportunity to integrate

Table III. Arizona's Position (Carson)

All figures are in acre-feet

Firm water available to lower basin [III(a) and III(b)]		8,500,000
California's limitation	4,400,000	
Nevada	300,000	
Utah and New Mexico	131,000	
Subtotal		4,831,000
Available for Arizona		3,669,000
Arizona's use of the Gila River		1,000,000
Arizona's "right" in main stream		2,669,000

the total lower basin plants well within the rights of Hoover Dam allottees and still develop the full potentialities of the river, and also to avoid the waste of capacity that results from integration where the main storage is downstream. The aim is to achieve the best over-all economy as a result of integration of the Colorado River facilities with those of all the systems supplying the entire market area including Arizona, Nevada, and Southern California.

CONFLICTING CLAIMS OF ARIZONA AND CALIFORNIA FOR WATER RIGHTS

By far the most important problem, in connection with the development of the river, that is pressing for solution is that of adjudicating the conflicting claims of Arizona and California as they have arisen out of their separate interpretations of the Colorado River Compact, the California Limitation Act, the Boulder Canyon Project Act, and the several contracts between the respective states and the United States Government. This article will try to give sufficient background of the facts, discussion, and contentions to bring about an understanding of the issues and the basis for the respective claims.

In his statement before the Senate Committee, Larson says,

> In the absence of a compact dividing among the various states involved, the water apportioned to the lower basin by the Colorado River Compact, the determination of Colorado River water available for diversion to the Central Arizona project, herein presented, is based upon interpretations by responsible officials of the state of Arizona. It is recognized that these interpretations are not the same as those of some other states in the Colorado River basin.

As a historical background it should be stated that, by 1922, the irrigation developments in Imperial Valley, which had begun to an important extent more than 20 years previously, had grown to the point where, in years of low runoff, they were using the entire flow of the Colorado River in the months of minimum flow. The prior right, so established by beneficial consumptive use, definitely limited the use of the stream by upper basin states, whose irrigation developments were lagging with respect to those in the lower basin. With projects such as the Boulder Dam being advocated, which might limit still further the states in the upper basin, and with the stream being an interstate, international, and navigable stream, the United States Government had jurisdiction, and the only feasible way to protect the upper basin and thus clear the way for further lower basin development was for an interstate compact to be formulated. This compact was signed in November 1922 by the commission and promptly ratified by all states except Arizona who ratified in 1944. The compact defines the upper and lower basins and makes allocations to each basin.

The compact defines the upper and lower basins and in article III paragraph (*a*) allocates to each basin the "exclusive beneficial consumptive use of 7,500,000 acre-feet of water per annum."

In article III paragraph (*b*) the lower basin is given the right to "increase its beneficial consumptive use" by one million acre-feet per annum.

Paragraph (*c*) of article III deals with obligations of the two basins under certain circumstances to supply water to meet the requirements of any future treaty with Mexico.

Article III paragraph (*d*) states,

> The states of the upper division will not cause the flow of the river at Lee Ferry to be depleted below an aggregate of 75,000,000 acre-feet for any period of ten consecutive years.

In making this provision, the commission was cognizant of the erratic flow of the river and was endeavoring to avoid having a condition develop where no water would reach the lower basin from the upper basin for occasional years during a dry cycle. The intent is that the minimum releases under such a program of delivery, added to water sources within the lower basin, will enable the lower basin to obtain its allotment.

Article VIII indicates that perfected rights to the beneficial use of water of the Colorado River are not impaired by the compact, and that the claims of the lower basin appropriators are to be satisfied from stored water.

The Boulder Canyon Project Act authorized the Secretary of the Interior to construct, operate, and maintain a storage dam, power plant, and incidental works at

Black Canyon or Boulder Canyon and the All-American Canal. Such construction was not authorized to be started until suitable contracts had been executed for sale of water and power, which would assure repaying the cost of the project with interest at four per cent together with covering maintenance, operation and replacements, and repayment of the canal investment, without interest under the provisions of the Reclamation Law. As the users of the All-American Canal were receiving stored water in satisfaction of their rights by prior appropriation, provision was made that there should be no charge for use, storage, or delivery of such water in the Imperial Valley and Coachella Valley.

The act also authorized a Tri-State Compact between Arizona, California, and Nevada, which never was consummated, but is of interest in that it indicates that for all provisions of use beyond Article III paragraph (*a*), Arizona and California are on a par.

California passed the Limitation Act in essentially the exact words quoted from the Project Act.

During 1930, contracts for the delivery of water to various contractors under the Project Act were consummated. Before such were made, however, the secretary demanded an agreement between the California water interests to set up priorities of rights. This agreement resulted in the priorities shown in Table II.

In its essentials, Arizona's position is expressed by its special attorney, Charles A. Carson (Table III).

In general Larson agreed with Carson. He indicated also that, based on long term averages, there is available 220,000 acre-feet more than allotted by the compact, and that Arizona is entitled to one quarter of that, four states being involved. However, James H. Howard, general counsel for the Metropolitan Water District for Southern California, in his testimony pointed out three erroneous assumptions in the Arizona interpretations:

1. That, by the terms of the California Water Limitation Act, California agencies are excluded from participation in the use of water referred to in Article III, paragraph (*b*), of the Colorado River Compact.

2. That the measure of beneficial consumptive use of waters of the Gila River in Arizona is the amount of depletion of the virgin flow of the river at its confluence with the Colorado River, and not actual "beneficial consumptive use."

3. That the 4,400,000 acre-feet of water apportioned by Article III, paragraph (*a*) of the Colorado River Compact, to which California is limited by the Project Act and the Limitation Act, is subject to further reduction by reason of evaporation and other reservoir losses, particularly at Lake Mead.

Howard's testimony substantiated California's claim that the one million acre-feet granted to the lower basin under the compact article III paragraph (*b*) is water that is to be shared alike by Arizona and California. He also showed why Arizona's consumptive use should be measured in terms of actual diversion less return flow, which is a value approximately one million acre-feet more than now claimed by Arizona. His discussions showed how the wording of the contracts and substitution of stored water for prior rights on the stream were incompatible with California's assuming storage losses.

Recalling the California priorities for water given in Table II and the long period of below average flows, it becomes apparent that the 1,200,000 acre-feet proposed to be taken out of the main stream for the benefit of the Central Arizona project would leave only about 300,000 acre-feet available to the Metropolitan Water District under its highest priority right and thus cut into even the 4,400,000 acre-feet of water available under article III, paragraph (*a*), of the Colorado River Compact. This is only one quarter of the total water, for which the district will have invested $274,000,000 to bring to the coastal cities of Southern California.

Those officials responsible for California's water supply for irrigation and for domestic purposes no longer can run the risk of having such water supply jeopardized by such acts of Congress as that which has been discussed. If the Colorado River is measured in terms of the needs of the Southwest, it is not adequate. If it is measured by those needs that communities are willing to pay for in order to be supplied it will be adequate. By "willing to pay for" is meant the development of projects on a basis that meets the standards of the Reclamation Law as used with its original interpretation. With this in mind, and with confidence that contracts with the government would not be jeopardized by future acts of Congress, $2^1/_2$ or 3 million people in the Southern California area constructed the Metropolitan Water District aqueduct to give insurance that water would be available for possibly 8,000,000 people to reside there. The cost of that project is almost exactly equal to the value of all the farm and ranch properties in the entire state of Arizona. To augment that economy in Arizona by not more than one-third, a project is being proposed of which even the irrigation features alone exceed the total farm values in the entire state. For this the Government will get back part of its money in 80 years and lose interest on all of it. California believes that such unfeasible irrigation projects will jeopardize its ultimate water supply, thus wasting its investment in the Metropolitan Water District aqueduct. A bill has been introduced into Congress to permit settlement through adjudication by the United States Supreme Court.

The Colorado River power projects are essential to the growth of Southern California but must be developed conservatively along lines of the original Boulder project to attract congressional support. These proposed projects at still greater distances cannot carry an undue amount of unfeasible irrigation. Neither can such power projects stand economically the diversion of water among them. The Bridge Canyon project by itself, and without undue support by the Hoover Dam project, would be an unfeasible power project, but when operated in conjunction with adequate upstream storage such as that afforded by Glen Canyon, and augmented by the future power developments which such storage makes possible, the entire Colorado River development can be a successful and useful project.

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